A Study On Impacts Of Surface Geometries On Boundary Layer Flows Of Nanofluids

SYNOPSIS

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1 Introduction

The different aspects of science and engineering can be easily understood by fluid mechanics. It is very important to have understanding and knowledge of the basic principles and concepts of fluid mechanics to investigate the system in which fluids are the working medium. In 1940, the crash of Tacoma Narrows Bridge witnesses of the possible consequences of ignoring the basic principle of fluid mechanics. The knowledge of fluid mechanics is required to design all types of fluid machinery such as turbines, fans, pumps, compressors, lubricating systems, shopping malls, aircraft for subsonic and supersonic flights, submarines etc. Fluid dynamics has vast range of applications such as in fluid mixtures and heat ex-changers, flying robots, aerospace industry, power generation, nanotechnology, wind energy and wind farms, etc. [1]-[2]. Boundary layer is a thin layer of a flowing gas or liquid in contact of a solid surface. In the advancement of fluid dynamics, the boundary layer is playing a vital role in the analysis of composite behaviour of fluids. In past few decades, the boundary layer flow problems have been extensively studied and the researchers are keenly involved in finding the similarity solutions for the flow past a boundary layer. It was Ludwig Prandtl [3], a German Scientist, who firstly studied the laminar flow over a flat plate with the effect of viscosity. He showed that for slightly viscous fluid, viscosity plays a prominent role in the boundaries and is negligible in the bulk of the flow. This is extremely useful concept that changed the mathematical properties of the original Navier-Stokes equations and solved these highly non-linear equations to a large extant. The Navier-Stokes equations are based on the principles of conservation of momentum and are used to represent low or high speed, incompressible or compressible, inviscid or viscous flows.

The foundation axioms of fluid dynamics are conservation laws, specifically:

- Equation of state :

$$p = \rho RT,$$

- Equation of continuity (Based on the principle of conservation of mass) :

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho v_j) = 0,$$

- Navier Stokes equations (Based on the principle of conservation of momentum) :

$$\rho \frac{D}{Dt}(v_i) = \rho f_b - \frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}[\mu(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} - \frac{2}{3}\frac{\partial}{\partial v_k}\partial x_k \delta_{ij})],$$

where ρ denotes the fluid density, μ is fluid viscosity, p is pressure, and f_b denotes body forces per unit mass. Boundary layer flow defines the lift and drag feature of solid surfaces and also give information on how a body will react to the adjacent flowing fluid. The skin fraction drag exerted on the object involved in fluid cannot be neglected. The boundary layer theory is helpful in the calculation of skin friction drag and explanation of physical behaviour of fluid flow. Under some particular conditions, a reverse flow can occur directly at the wall, due to which a separation of the boundary layer takes place and the formation of large or small eddies at the back of the body occur. Separation occurs not only in flow past a body but also occurs in a flow through a duct. Boundary layer theory helps to understand the process involved in maximum lift of aerofoil where separation is also important. This concept of boundary layer flow has been very important in the field of fluid dynamics which has derived the interest of many researchers. Physicists and engineers have written several excellent books covering different aspects of boundary layer theory to help students and researchers to acquire a deeper understanding in which the best known is Hermann Schlichting's Boundary layer Theory. Prandtl's student, Hermann Schlichting [4], conducted research on different conditions of flow with friction. Blasius [5] solved boundary layer flow equation over a flat plate and a circular cylinder. For flat plate he obtained more accurate solution for skin friction drag than appeared in Prandtl's original paper. The equation that applies to a flat plate at zero attack angle is known as the Blasius equation.

Sakiadis [6] obtained the same equation as obtained by Blasius [5] for the boundary layer flow on a moving flat plate in a quiescent fluid with different boundary conditions. Sakiadis [6] was the first who studied the boundary layer flow on a constant speed moving plate and Crane [7] extended this concept to a stretching sheet with linearly varying surface speed. He presented an exact solution for the steady two dimensional flow over

stretching surface in quiescent fluid. There are wide ranges of applications of boundary layer flow in designing of different objects which have to overcome the fluid flow for smooth working. Some of those are automobiles, aerofoils of airplanes, species transport, golf ball aerodynamics, heat transfer enhancement, modelling and analysis of weather etc.

Because of its engineering application, a comprehensive research on boundary layer flow over a stretching surface has been taken since pioneering work of the Sakiadis [6]. The flow over a stretching sheet was firstly considered by Crane [7] who conferred an exact analytic solution over a stretching plate in a quiescent fluid. A stretched sheet collaborates with the ambient fluid both thermally and mechanically during the construction process. Chen and Char [8] studied the heat transfer aspect in case of suction or blowing on a stretching sheet with variable surface temperature. Boundary layer flow over a stretching surface is often seen in many engineering disciplines. Stretching sheet is generally in-extensible. Flow due to a stretching surface involves spinning fibers, glass blowing, cooling of a layer metallic plate in a bath. Boundary layer flow over a stretching surface appears in different areas, for example, the boundary layer along liquid film and condensation process, boundary layer along a material handling conveyor, glass fiber process etc. Appreciable efforts have been conducted towards the study of the boundary layer flow and heat transfer over a stretching sheet because of its various industrial applications such as manufacturing, electronics, aerospace and transportation industries. The analysis of boundary layer flow and heat transfer as a result of stretching surface has numerous applications in industrial and manufacturing processes e.g. in polymer expulsion, metal expulsion and metal extrusion, wire drawing, drawing of copper wires, paper production, glass fiber, paper industries, textile industries, drawing of plastic sheets. In many engineering processes, boundary layer behaviour over a moving continuous solid surface is an important type of flow. Over the past decades, laminar boundary layer flow past a wedge has been of big interest. The wedge is triangular shaped tool that can be used in the process of separating the two objects in which an object is held in a plane and the other object is lifted up. It converts the lateral force into a transverse splitting force. Flow, heat, and mass transfer along a wedge have achieved extensive attention because of its wide range of applications in industries and it has an important role in several natural and technological processes. The governing partial differential equations are transformed into ordinary differential equations with the help of similarity transformation for developing the

Ludwig Prandtl boundary layer theory and that equations now are known as Falkner-Skan flow equation. Falkner and Skan [9] investigated the concept of the wedge phenomenon for two dimensional flow and derived the general equation for self- boundary layers. The Falkner–Skan solution for laminar boundary-layer flow over a wedge is modified to allow for a slip boundary condition. Slip flow over a wedge was analysed incorporating a slip boundary condition. The relative decrease in skin friction became larger as the wedge angle increased. It is interesting to note the boundary-layer problems for two dimensional steady and incompressible laminar flow passing a wedge in the relevant field of aerodynamics. In exponentially stretching surface, it is assumed that flow field obeys the conventional no slip condition at the sheet. But there are some situations where such condition is not appropriate. Specially, for most non-Newtonian fluid,the no slip condition is inadequate. For example, polymers melt often exhibits macroscopic wall slip and that in general is governed by a non-linear and monotone relation between the slip velocity and traction. The fluids exhibiting boundary slip find application in the polishing of artificially heart valves and internal cavities. The boundary layer also plays a major role in heat transfer between a body and the fluid around it. A few thoughts have been expected to clear up the advanced heat transfer behavior of nanofluids. The term nanofluid was firstly identified by Choi and Eastman who stated the distribution of nanometre sized particles in a base fluid. Nanofluid is a combination of nano particles in a base fluid to enhance the thermal performance of the fluid. Nano particles are relatively close in size to the molecules of base fluid in comparison to the milli and micro sized particles and therefore, can realize very stable suspension over long periods of time. The aim of using nanofluids is to attain higher values of heat transfer coffiecient as compared with that of the base liquid. A nanofluid is a colloidal dispersion of a two-phase system where nanoparticles are in solid phase and the base fluids are in the liquid phase. Nanofluid is environment friendly and also provides better efficiency than the fluids used previously. The addition of nanoparticles in a conventional fluid increases the thermal conductivity. Heat transfer enhancement during a work can improve the quality of the product, minimize the time of manufacturing, and extend the life of a machine. Thermal conductivity is one of the important characteristics of fluids and solids. It is the power of a material to conduct heat. High thermal conductivity implies high heat transfer. Heat transfer component of fluids can be effectively improved by the application of nano fluids. Nano phase powders have much larger relative surface area and a high potential for

heat transfer enrichment than the micron sized particles. A few researches accepted to add nanoparticles into fluid to form effective heat transfer fluids. There are many researches whose focus is on those nanofluids which are having different nanoparticles with different volume concentration and size used in heat transfer applications. Nanofluid is a colloidal mixture of nano sized particles in a base fluid to enhance the heat transfer characteristics suited for practical applications. Currently a few latest inventions analysed the utilisation of nano particles in heat transfer applications. Nanoflluid is the distribution of nano-sized metallic particles in the ordinary heat transfer fluids. Nano fluids are available in the various forms such as metals, metal oxides, ceramics, semiconductors and carbon nano tube. Temperature plays a vital role in heat transfer characteristics of nanofluids along with nano particles size and concentration [10]-[11]. Several models have been recommended to access the thermo physical properties of the nano fluid such as viscosity, thermal conductivity etc. Thermal conductivity of nanofluids is mainly increased by the Brownian motion and interfacial layer formation. These two plays major role in increasing thermal conductivity of nanofluids. Buongiorno [12] considered seven slip mechanism i.e. inertia, Brownian diffusion, thermophoresis, diffusiophoresis, Magnus effect, fluid drainage and gravity which can produce relative velocity between the nanoparticles and the base fluid. Out of these seven slip mechanism, Brownian diffusion and thermophoresis are much important in nanofluids. Below is the governing equations for the Buongiorno's model for the flow of nanofluids:

Buongiorno Model

The continuity equation for the nanofluid is :

$$\nabla . v = 0,$$

where v is the nanofluid velocity. This equation is identical to continuity equation for a pure incompressible fluid. The continuity equation for nanoparticles in the absence of chemical reaction is :

$$\frac{\partial \Phi}{\partial t} + v.\nabla \Phi = -\frac{1}{\rho_p} \nabla . j_p,$$

where t is time, j_p is the diffusion mass flux for the nanoparticles and represents the nanoparticle flux relative to the nanofluid velocity v. If the external forces are negligible, j_p can be written as the sum of only two diffusion terms, i.e., Brownian diffusion and

thermophoresis :

$$j_p = j_{p,B} + j_{p,T} = -\rho_p D_B \nabla\Phi - \rho_p D_T \frac{\nabla T}{T},$$

Now, when we put these values in continuity equation, then the equation becomes :

$$\frac{\partial\Phi}{\partial t} + v.\nabla\Phi = \nabla.[D_B\nabla\Phi + D_T\frac{\nabla T}{T}],$$

This equation states that the nanoparticles can move homogeneously with the fluid, but they also possess a slip velocity relatively to the fluid which is due to Brownian diffusion and thermophoresis.

The momentum equation for the nano fluid with negligible external forces is :

$$\rho[\frac{\partial v}{\partial t} + v.\nabla v] = -\nabla P - \nabla.\tau,$$

where P is the pressure. The stress tensor, τ, can be expanded assuming Newtonian behavior and incompressible flow :

$$\tau = -\mu[\nabla v + (\nabla v)^t],$$

where the subscript t indicates the transpose of ∇v. If the viscosity μ is constant, the above equation becomes the usual Navier-Stokes equation. The energy equation for the nanofluids is given by :

$$\rho c[\frac{\partial T}{\partial t} + v.\nabla T] = \nabla.\kappa\nabla T + \rho_p c_p[D_B\nabla\phi.\nabla T + D_T\frac{\nabla T.\nabla T}{T}],$$

where ρ is nanofluid density, D_B is brownian diffusion, κ is thermal conductivity, v is nanofluid velocity, c is nanofluid specific heat, D_T is thermal diffusion coefficient, T is nanofluid temperature.

The scope of the research on nanofluid is extensively increased because of the wide application of nanofluid such as automotive system, domestic refrigerators, industrial cooling system, solar devices etc. On account of significant increase in thermal conductivity, nanofluids found practical utility in mass transfer enhancement, technological, industrial and pharmaceutical processes. Nanofluids can be used to improve

heat transfer and energy efficiency in a variety of thermal systems. Nanofluids are used as coolants in computers, auto-mobile transmission, transformers, electronic cooling, drilling fluids, solar water heating, submarines, high power laser diodes, vehicles and many other electronic devices. This will also reduce environmental pollutants because smaller heating units use less power, and the heat transfer unit has less liquid and material waste to discard at the end of its life cycle. Nanofluids have wide range of applications in space and defence fields for designing different military devices, space technology and nuclear reactors. Some special kinds of nano particles have antibacterial properties so that they can be utilized in treating several diseases like cancer infected tissues. The use of nanofluids in extensive range of applications appear encouraging. The development of this field is disadvantaged by (1) lack of agreement of results obtained by different researchers,(2) lack of stability of the nanofluids, (3) poor characterization of suspensions,(4) lack of theoretical understanding of the mechanisms responsible for changes in properties, (5) high cost of nanoparticles. Since the field of nanofluids is still in the beginning stage but the future of nanofluid seems bright. It is clearly on the basis of review of the recent literature that the significant efforts are made to improve the general performance and potential applications of nanofluids. Hence, a multi-disciplinary approach comprising researchers such as thermal engineers, chemical technologist, material scientist, chemists, and physicists needs to be undertaken [13]-[15].

2 Literature Review

Vajravelu and Mukhopadhyay [16] studied a wide variety of mathematical problems, appearing in the areas as diverse as fluid mechanics, mechanical engineering, chemical engineering, theoretical physics and aerospace engineering and these problems have been solved by means of analytical or numerical methods.

Muhmmad et al. [17] and Ishak et al. [18] investigated numerically the boundary layer flow over a moving plate in a nanofluid with the presence of viscous dissipation. It is shown how the Prandtl number, plate velocity parameter, Brownian motion parameter, thermophoresis parameter, Eckert number and Lewis number affect the value of reduced Nusselt and Sherwood number and the skin friction coefficient as well as the concentration

and temperature profiles. As conclusion, the thermal boundary layer thickness depends strongly on these parameters.

Nabil et al. [19] studied the advancement of boundary layer flow with mass transfer through porous medium over a moving permeable flat plate with variable wall concentration in the existence of first order chemical reaction. The non- linear system of non- linear differential governing equation is solved numerically by both Keller box method and the method based on fourth order Runge- Kutta iteration scheme with shooting method. It is found that the existence of dual solution exists when the variation of a velocity profiles and the directions.

Alinejad and Samarbakhsh [20] numerically studied the flow and heat transfer aspects of incompressible viscous flow over a non-linearly stretching sheet in the presence of viscous dissipation. They also studied the effect of various values of Prandtl number and non-linear stretching parameter.

Bhattacharyya [21] have analyzed the effects of partial slip on steady boundary layer stagnation-point flow of an incompressible fluid and heat transfer towards a shrinking sheet. This investigation numerically explores the conditions of the non-existence, existence, uniqueness and duality of the solutions of self-similar equations. Due to the increase of slip parameter (d), the range of velocity ratio parameter (c/a) where the similarity solution exists, increases.

Khan and Pop [22] investigated numerically the problem of laminar fluid flow which results from the stretching of a flat surface in a nanofluid. He used a model for nanofluid that incorporates the effects of Brownian motion and thermophoresis. It has been observed that the reduced Nusselt number is a decreasing function of each dimensionless number, while the reduced Sherwood number is an increasing function of higher Pr and a decreasing function of lower Pr number for each Le, Nb and Nt numbers.

Ibrahim [23] and Mahapatra and Gupta [24] examined the melting heat transfer in mhd stagnation point flow of a nanouid past a stretching sheet. Boundary layer theory is employed to simplify the system of partial differential equation of motion, energy and concentration to three coupled non-linear ordinary differential equations. The effect of pertinent parameters on different flow fields are determined and discussed in detail through several plots and tables. The numerical results are obtained for velocity, temperature and

concentration profiles.

Etwire [25] revealed the effect of radiation and chemical reaction on magneto hydrodynamics stagnation point flow over a porous stretching surface with connective thermal boundary condition. The effects of suction parameter, velocity ratio parameter, magnetic field parameter, radiation parameter, Prandtl number, Schmidt number, biot number and reaction rate parameters on the flow field were examined.

In the direction of a stretching sheet, a computational dynamics on the hydrodynamics stagnation point flow was studied by Makinde and Charles[26] and Mansur and Ishak [27] and wind up that the cooling rate of a stretching sheet in an electrically conducting fluid could be composed and a final product with desired components could be obtained.

Rangi and Ahmad [28] analysed that the curvature of stretching cylinder is very basic parameter affecting both the flow and temperature field. Curvature helps to enhance the heat transfer in case of thermal conductivity. The reduction in fluid viscosity accelerates the rate of convection heat transfer.

Vajravelu [29] studied the flow and heat transfer characteristics in a viscous fluid over a non-linearly stretching sheet. It has been observed that the equations of conservation of momentum, mass and energy, which govern the flow and heat transfer, are partially decoupled using a similarity tansformations which is different from that of the linearly stretching sheet problem and the numerical results shows that the heat flow is always from the stretching sheet to the fluid.

Bhattacharya [30] and Reddy et al. [31] analyzed the steady two-dimensional boundary layer flow and reactive mass transfer past an exponentially stretching sheet in an exponentially moving free stream. It is found that the momentum boundary layer thickness is considerably smaller than that of stagnation point flow over stretching sheet. Due to increase of Schmidt number and reaction rate parameter, the mass transfer considerably enhances.

Mukhopadhyay [32] and Murthy et al. [33] presented the boundary layer flow and heat transfer towards a porous exponential stretching sheet in the presence of a magnetic field. He considered the velocity slip and thermal slip instead of no-slip conditions at the boundary. It is found that the horizontal velocity decreases with increasing slip parameter as well as with the increasing magnetic parameter. Temperature increases

with the increasing values of magnetic parameter. Temperature is found to decrease with an increase of thermal slip parameter. Thermal radiation enhances the effective thermal diffusivity and the temperature rises.

Hossain et al. [34] theoretically investigated the effect of temprature viscosity and thermal conductivity on forced covection boundary layer flow about a wedge. The local non-similarity equations governing the flow in the leading edge as well as in the asymptotic regime are solved using suitable perturbation methods. They concluded that in the entire ξ range, both the local skin friction coefficient and the local Nusselt number increases as ξ increases for all ε, v and m. The local skin friction coefficient and the local Nusselt number decrease with the increase of ε for all ξ.

Bhogare and Kothawale [35] investigated that nanofluids are potential heat transfer fluids with enriched thermophysical properties and heat transfer performance can be practiced on many devices for better performances. They also concluded that the compact cooling system is more beneficial with smaller and lighter automobile radiators.

Choi and Eastman [36] have proposed an innovative new class of heat transfer fluids can be engineered by suspending metallic nanoparticles in conventional heat transfer fluids. He analyzed that the resulting "nanofluids" are expected to exhibit high thermal conductivities compared to those of currently used heat transfer fluids.

Tiwari and Das [37] studied the behavior of nanofluids numerically convective a two-sided lid-driven differentially heated square cavity to gain insight into convective recirculation and flow processes induced by a nanofluid .A model is developed to analyze the behavior of nanofluids taking into account the solid volume fraction v. It is found that both the Richards number and the direction of the moving walls affect the fluid flow and heat transfer in the cavity copper-water and solid volume fraction v is varied as 0.0.

Dharmalingam et al. [38] investigated about the latest research and development in Nanofluids and also explained its heat transfer mechanism. Although the usage of nanouid in practical application is demanding because of sedimentation development and clogging in flow path.

Das et al. [39] and Das et al. [40] discussed the unsteady boundary layer flow of a nanouid with thermal radiation over a heated stretching sheet. Because of the time dependence of the stretching velocity, the surface temperature and free stream velocity

there is unsteadiness in the flow field. It is found that in the presence of Brownian motion, the heat transfer rate at the surface increases but in case of thermophoresis reverse effect occurs.

Gupta et al. [41] discussed the important results regarding the improvement in the thermophysical properties of nanouids. The influence of important parameters like particles (loading, material, size, and shape), base fluid type, temperature, additives, and pH value has been considered.

Hussain et al. [42] investigated that thermal conductivity and viscosity increases with the increase in concentration of the nano fluid. All the studies confined enhancement of the heat transfer coefficient with an increase in concentration. It is observed that the concentration of nanouids, the particle size and shape,the operating temperature,together with the nanoparticle dispersed in the base liquid, have significant influence on the heat transfer coefficient.

Lee et al. [43] revealed that the pH level and addition of surfactant affect thermal conductivity of nanouids during nanouids preparation stage.

Peng et al. [44] found that the pure refrigerant is smaller than the frictional pressure drop of refrigerant based nanouids flow boiling inside the horizontal smooth tube. It decreases with the decrease of the mass fraction of nanoparticles. The maximum enrichment of friction pressure drop can reach 20.8.

Xuan and Li [45] found a preparation method of nanofluids. Several sampled nanofluids have been prepared by directly mixing nanophase powders and base fluids with this method and that reveals the possibility of practical application of the nanofluids. The nanouid shows great potential in enlarging the heat transfer process. The thermal conductivity of nanofluids is affected by the volume fraction, directions, shape and properties of the nano particles. The hot-wire method has been used to measure the thermal conductivity of nanofluids.

3 Research Gap Identification

In this research work, the concept of two dimensional boundary layer flows of nanofluids over curved stretching sheet, exponential stretching surface and symmetric wedge will be explored. Boundary layer flows of nanofluids are in the spotlight for the years and plenty of work has been done in this direction. Still there is a huge gap in the literature to be filled and many concepts are still untouched. The impact of various major factors such as particle size and shapes, clustering of particles, temperature of the fluid is still not explored satisfactorily. The work will display how the velocity , temperature and concentration profiles influenced by various dimensionless parameters and nano particles volume fraction. The prime concern of this work is to introduce such concepts and theories that will helpful to give a perfect control on the flow characteristics of fluids and enhance mass and heat transfer rates.

4 Objectives

In this research work, we will focus ourselves in the understanding of boundary layer behavior of nanofluids flows over distinct geometrical surfaces. The main objectives of present study will be :

- To investigate the influence of nanofluid parameters, convection, magnetic field strength, porous medium permeability on flow of nanofluid past stretching sheet.
- To understand the influence of controlling parameters such as convection, magnetic field and porous medium permeability on flow past the exponentially stretching sheet.
- To examine the effects of related physical parameters on flow past wedge.

5 Proposed Methodology

Firstly, physical problems which we will consider, will be transformed into partial differential equations with initial and boundary conditions.

Secondly, the obtained system of equations will be made dimensionless by using some non-dimensional techniques.

Thirdly, the obtained non-dimensional highly non-linear system of equations will be solved either by using numerical method or analytic techniques.

After that, computer codes will be formulated for the used computational methods in MATLAB /MATHEMATICA. The convergence and stability conditions will also be obtained for the applied computational methods. Lastly, the achieved solutions will be presented in the forms of graph and tables.

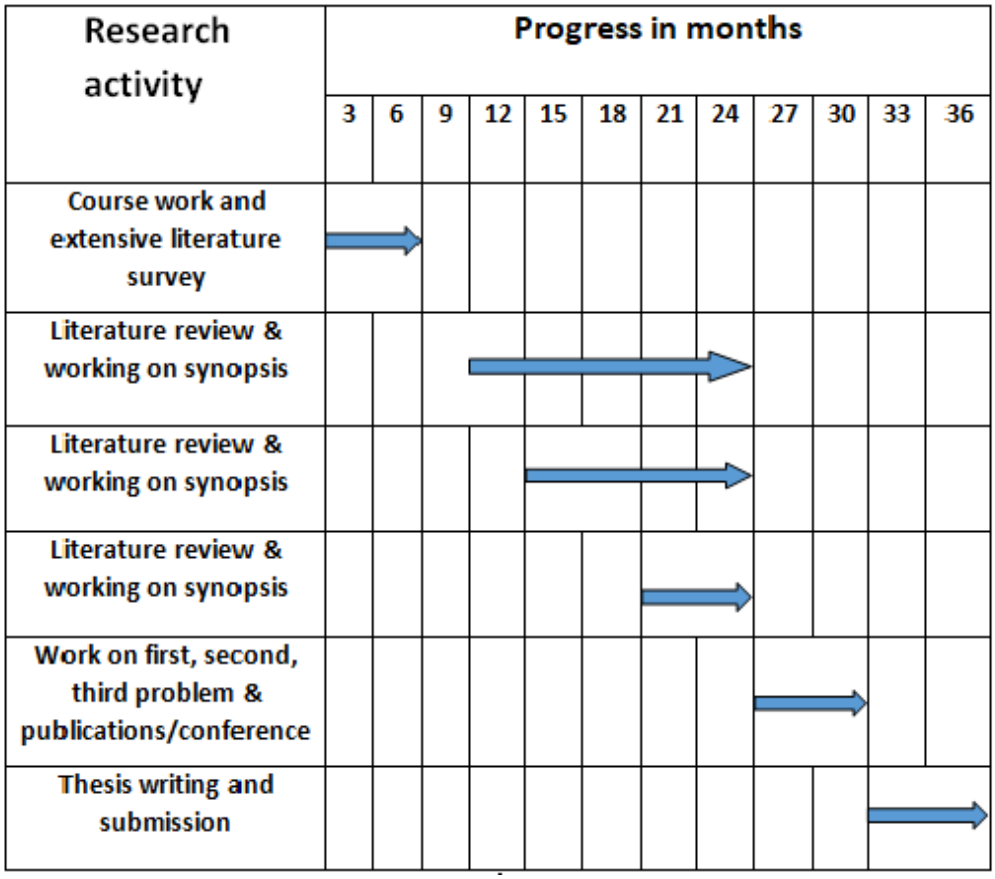
6 Thesis Outline

Considering these objectives in mind, chapters 2, 3, 4 and 5 will be constructed.

Tentative chapter plan of this thesis is as under:

Chapter 1	Introduction
Chapter 2	Literature review
Chapter 3	Flow of nanofluid over a curved stretching sheet
Chapter 4	Flow of nanofluid caused by exponential stretching of surface
Chapter 5	Nanofluid flow over a symmetric wedge
Chapter 6	Conclusions,implications and future work

Research plan schedule:



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